ASSESSMENT OF GROUNDWATER INTRINSIC VULNERABILITY USING GIS-BASED DRASTIC METHOD IN ISLAMABAD, CAPITAL TERITORY, PAKISTAN

BY

FAYAZ ULLAH

Department of Earth and Environmental Sciences bahria university Islamabad

APRIL 2024

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A thesis presented to meet of the requirements for the award of the degree of Master of Science (Geology)

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APPROVAL OF EXAMINATION

Scholar's Name: "Mr. Fayaz Ullah" Registration No: "82949" Program of Study: MS Geology

Thesis Title: "ASSESSMENT OF GROUNDWATER INTRINSIC VULNERABILTY USING GIS-BASED DRASTIC METHOD IN ISLAMABAD, PAKISTAN"

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DEDICAITON

I dedicate this thesis to my beloved parents and respectable teachers whose prayer and guidance has always been wheels for me that has always helped me to travel in this competitive era.

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ABSTRACT

The UN included a target on clean water to its list of sustainable goals in response to the strain on the planet's freshwater resources. This goal aims to address the availability of clean water on a worldwide scale. Groundwater contamination was brought on by the widespread application of fertilizers and the use of wrong dumping sites in the Islamabad. The DRASTIC model, which is based on geographic information systems (GIS), was utilized in Islamabad to assess the groundwater's susceptibility. The vulnerability index of DRASTIC model ranged from 275 to 900. The values near to 900 indicates more vulnerable zone while the values around 275 showed susceptibility towards the contamination. The area was classified into 5 zones in equal intervals. Among the zones are one with a very low vulnerability spanning 22 km2 or 2% of the entire research region and with a DRASTIC index between 275 and 400. The area covered by the low vulnerability zone index, which varied from 400 to 525, was 306 km2, or 28% of the total area. The moderate vulnerability zone index (525–650) covered the greatest area, 500 km2, or 47% of the entire area. The high vulnerability index (650 - 775) covered 221 in km^2 and 21 in percentage area and the very high vulnerability zone index (775 - 900) covered 26 km^2 area indicating 2% of the study area. To verify the DRASTIC indices, a spatial distribution map of nitrate concentration was created. The results of the regression analysis indicate a weak relationship between groundwater vulnerability and the distribution of nitrates in area. It suggests that nitrate is not the contamination's vulnerability source in Islamabad; rather, the nitrate content was comparatively greater in the zone with a very high DRASTIC results. Islamabad nitrate concentration ranged from 0 to 2.5 ppm. The index map will function as a foundational study for the establishment of safe zones for groundwater extraction and the control of the current environmental standards' deterioration in this region. The first task towards which should be handled in very high vulnerability areas should be the treatment of the stream from contaminations which are accumulating into the Rawal lake and the use of proper chemical which are not harmful for ground water in NARC (National Agriculture and Research Center).

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Introduction

1.1 Background

In both human existence and civilization at large, water is essential. Groundwater and surface water are essential for maintaining the ecosystem and environment, as well as for cultural, recreational, social, health, and economic activities (Anornu et al., 2012). The water above the ground is known as surface water, while groundwater is located beneath the surface of the Earth in rock formation fissures, soil pore spaces, and other areas. Because of the fast population expansion, surface water is becoming less abundant and of higher quality over time, making groundwater the most dependable source of high-quality water (Anornu et al, 2012). The need for groundwater has increased as a result of issues brought on by the Impacts of surface water contamination and climate change from industrialization, rapid population expansion, and irrigation techniques (Anornu et al, 2012).

The most important source of water in the planet is groundwater (Tirkey et al, 2013). It supplies over 80% of the world's useable water storage and makes a significant contribution to industrial, municipal, and agricultural applications, particularly in places without alternative water sources (Shirazi et al, 2012). Since groundwater is the world's main supply of drinking water, its quality is just as vital as its quantity and availability (Rahman, 2008). According to Kemper (2004), Groundwater is essential to the daily lives of nearly two billion people worldwide. Because groundwater is less susceptible to pollution than surface water, it is a valuable source of water (EPA, 1985). Regrettably, human activity, wastewater released from agricultural and industrial sources, and underlying bedrock can all lead to contamination of groundwater (Babiker et al., 2005). The tendency of contaminants injected into the topmost layer of the aquifer or onto the earth's surface to contaminate the groundwater supply is referred to as "groundwater vulnerability" (Javadi et al., 2010; Shirazi et al., 2012). According to Tirkey et al (2013), the basis for the research of groundwater is the idea that groundwater's vulnerability to contamination changes with land area and is related to land use activities. Groundwater pollution can result from any action that involves the possible discharge of chemicals or waste materials into the environment. Groundwater pollution results from the large volumes of household, agricultural sewage, and industrial that are discharged into the environment, as a result of rapid population expansion and industrialization (Rahman, 2008). Compared to contamination in surface waters, groundwater pollution is more challenging to detect and address. Following discovery, remediating contaminated groundwater could take decades, centuries, or even longer (Todd, 1980; Rahman, 2008).

An international problem, excessive nitrate (NO^3) concentrations in groundwater are usually linked to intensive farming, unclean high-density housing, and the irrigating of land with liquid manure (Keeney, 1986; Eckhardt and Stackelberg, 1995; Spalding and Exner, 1993). When nitrogen that has been spread over the earth's surface seeps into the subsurface, it contaminates groundwater. Fertilizers that contain large amounts of nitrogen are known to boost crop yields. Nevertheless, nitrogen from fertilizer enters groundwater as NO^3 through precipitation penetration, irrigation, and other mechanisms when it surpasses plant requirement and soil absorption capacity (Meisinger et al., 1991; Shamrukh et al., 2001). Increased NO^3 concentrations in groundwater can cause eutrophication and reduce the fertility of the soil layer above them when groundwater is released into surface water at springs, endangering both human and animal health (McClay et al., 2001). Large concentrations of NO^3 in water can have an adverse effect on human health, even if minute amounts of NO^3 in water can be harmless. Given that the primary source of drinking water is groundwater, consuming too much NO^3 from the groundwater can be dangerous to one's health. High levels of NO^3 in the body can result in methemoglobinemia, also referred to as "blue baby syndrome." Among pregnant women with low stomach acidity, methemoglobinemia is most frequent and infants under six months old (Messier et al., 2014). The Environmental Protection Agency (EPA) set a maximum level of NO^3 contamination for drinking water of 10 mg/L as a result, above which hazardous effects of NO^3 in groundwater occurs (EPA,1995).

Numerous techniques have been established to evaluate the possibility of NO^3 or other contaminants contaminating groundwater. Three categories can be used to classify these techniques: Statistical methods, index methods and overlay, and process-based methods (Tesoriero et al., 1998; Thirumalaivasan et al., 2003). Techniques known to influence the flow of pollutants from the ground surface to the water table are combined in overlay and index approaches, to construct a vulnerability index map using predetermined vulnerability indices (Tirkey et al., 2013). In contrast to Process Based Methods, which employ a structured series of procedures or activities intended to evaluate groundwater susceptibility, Statistical Methods mainly employ statistical analysis to ascertain the correlation between the spatial features and the contaminants found in groundwater. The "DRASTIC" model, classified as an Overlay and Index method (EPA, 1993; Thirumalaivasan et al., 2003), is one of the most widely used techniques for mapping groundwater susceptibility the urban Lei River has a drainage area of about 211 km^2. The remaining 55% of the population resides in Rawalpindi, home to 3 million people, and Islamabad, home to roughly 3 million people. Rawalpindi's flooding problems are getting worse as a result of Islamabad's growth without considering its hydrogeological structure. Even after the 1994 drought, groundwater is still used for private purposes without centralized legal monitoring (Malik, 2000).

The Rawal River, the Soan River, and the Korang River are just a few of the rivers and streams that drain Islamabad, which is a city in the Indus River basin. Both rainfall and melting from the Himalayas feed these rivers. The alluvial deposits that surround the city contain a large volume of groundwater that is also present there (Wahab et al., 2012).

Water for the city is mostly provided by the Rawal Dam, which is roughly 30 km away from Islamabad. The dam serves as a water storage facility for the city and collects water from the Rawal River. 2015 (Abbas et al., 2015). Before being provided to the city, the water from the Rawal Dam is processed at the Rawal Water Treatment Plant. The treatment facility cleans the water of silt, germs, and other impurities (Basharat, 2019).

The Islamabad Sewage Treatment Plant handles the city's sewage. Solids, bacteria, and other pollutants are eliminated from the wastewater at the treatment facility. Afterward, the Rawal River receives the treated wastewater discharge (Aazizullah et al., 2011). Figure 1.1 shows the surface hydrology of islambad.

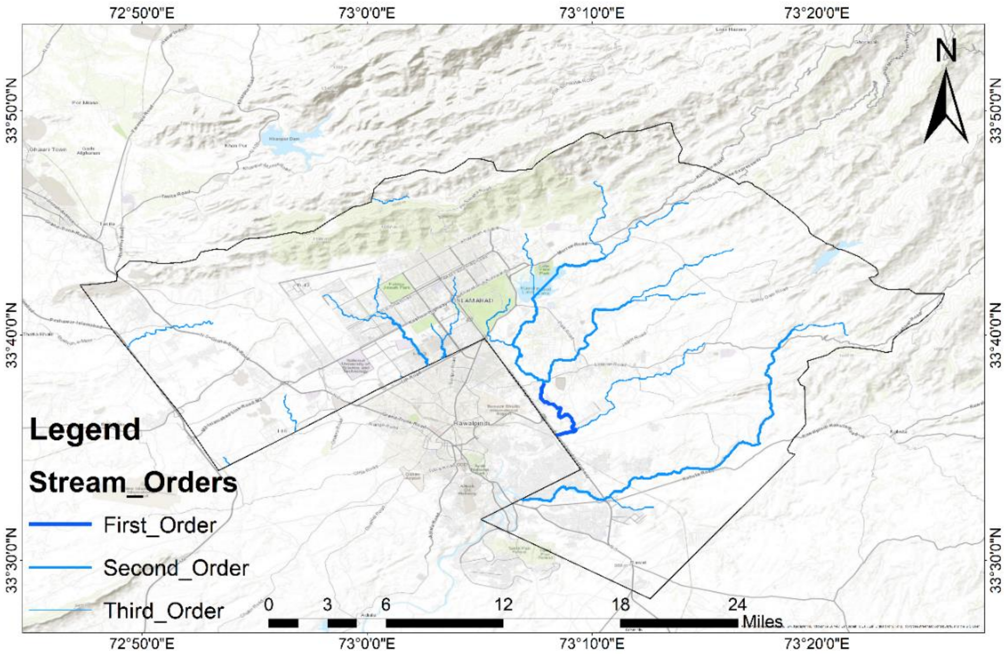

Figure 1.1 Surface Hydrology map of Islamabad

1.2 Previous Studies

International studies have shown a strong correlation between urbanization and groundwater vulnerability (Srinivasan et al., 2013). Urban areas tend to have higher levels of impervious surfaces, such as roads and parking lots, which reduce infiltration and increase runoff (Hubbart, 2009). This can lead to contamination of groundwater sources, as well as decreased recharge (Hubbart, 2009). Additionally, urban areas are often located in areas with naturally vulnerable aquifers, such as those with shallow water tables or sandy (Hubbart, 2009).

In the case of Islamabad, several factors contribute to the city's groundwater vulnerability. The city is located in a semi-arid region with a variable climate, which can lead to fluctuations in groundwater levels (Ahmed et al.,2018). Additionally, the city's geology includes both alluvial and karstic aquifers, which have varying levels of vulnerability to contamination (Shabbir and Ahmad, 2016).

International studies have also shown that climate change can exacerbate groundwater vulnerability (Mendieta-Mendoza et al., 2021). Rising temperatures can lead to increased evaporation, which can concentrate contaminants in groundwater (Kumar 2012). Additionally, more extreme weather events, such as floods and droughts, can also contaminate groundwater sources (Hrdinka et al., 2012).

Islamabad is particularly vulnerable to climate change, as it is located in a region that is expected to experience more frequent and severe heat waves and droughts (Ahmed et al., 2023; Pachauri et al., 2014).

These factors could lead to increased groundwater contamination and decreased recharge rates (Wick and Heumesser, 2012).

In order to solve Islamabad's issues with groundwater vulnerability, it is important to implement a comprehensive water resources management plan (Shabbir and Ahmad 2016). This plan should include measures to reduce groundwater contamination, increase recharge rates, and improve water conservation practices (Shabbir and Ahmad, 2016). Additionally, it is important to raise awareness about the importance of groundwater protection among the city's (Shabbir and Ahmad, 2016).

1.3 Background Information

In the US, the EPA helped develop the DRASTIC model, which uses a vulnerability index to assess aquifer risk in a range of hydrogeologic scenarios (Aller et al., 1987; Al-Rawabdeh et al., 2013; Babiker et al., 2005.). All of the primary geology and hydrologic elements that influence the flow of groundwater into and out of a zone or region are combined to form a hydrogeologic setting.

One of the most popular models for determining how vulnerable groundwater is to possible pollutants is DRASTIC (Al- Rawabdeh et al., 2013). This is a model that uses weights and ratings to combine a number of variables to create the intended vulnerability index map for a selected area. In order to construct the vulnerability map, DRASTIC uses a seven parametric system: D:

Water depth; R: Net recharge; A: Aquifer media; S: Soil media; T: Topography; I: Vadose zone impact; and C: Hydraulic conductivity. A detailed description of DRASTIC parameter is given in Table 1.1.

Table 1.1 A thorough explanation of the DRASTIC parameters

Parameters	Explanation
D	The deepness of an aquifer that is restricted is measured from the earth's surface to the water table or its confining layer.
R	The quantity of water discharged onto the surface of the earth that seeps into aquifer is known as net recharge.
A	The kind of the subsurface rock that serves as the aquifer is referred to as aquifer media.
S	Vadose zone’s head part is known as the soil media, characterizes the properties of the soil cover.
T	Topography refers to the shifting inclination of the earth's surface.
I	The term "vadose zone" impact refers to the dry zone over the water table.
C	The capacity of water to move through the aquifer's substance is known as hydraulic conductivity.

The determined DRASTIC index will display the relative groundwater vulnerability to any contamination. Different government, semi-government, and private organizations provided different kinds of data for different parameters. Extensive field surveys were conducted in order to gather information and confirm information obtained from secondary sources. The research employed ESRI's ArcGIS 10.8 to digitize the maps, process and interpolate the data, and produce a final susceptibility map.

These characteristics are given variable ratings according on the ranges or importance of the media kind, and constant weights based on their potential for pollution. Several academics throughout the world have assessed the vulnerability of aquifers and groundwater using the DRASTIC model (Saidi et al., 2010; Neshat et al., 2014). Fritch et al (2000) assessed the vulnerability of the USA's

Paluxy aquifer in central Texas to contamination, using DRASTIC. Kakamigahara Heights, Gifu Prefecture, and Central Japan's aquifer susceptibility were assessed by Babiker et al (2005) using the DRASTIC model. The model was also utilised by Jamrah et al (2008) as part of their analysis of the coastal region of Oman's groundwater susceptibility. Geographical maps displaying high, moderate, and low susceptibility areas are produced by DRASTIC models and may be investigated further at individual sites.

However, the DRASTIC model is inflexible when it comes to allocating rates and weights according to its specifications, which occasionally leads to inaccurate evaluations (Rupert, 2001). Researchers have identified certain drawbacks, such as the usage of uniform weights and rating values across the board due to the model's failure to consider the effects of local geology, topography, and land cover features (Javadi et al., 2011). Nevertheless, in order to more effectively point out this problem, Scientists have improved the way that distinct hydrogeologic and land cover features of a region are represented by utilizing various modifications of the original DRASTIC model (Babiker et al., 2005; Thirumalaivasan et al., 2003). Three possible forms for the alterations are as follows: (I) adding new parameters; (II) eliminating old ones; and (III) adjusting the weights and ratings that have been allocated. Groundwater flow, groundwater flow rate, and groundwater recharge source were among the data sources that Brown (1998) added to the DRASTIC criterion when examining the risk assessment of the Heretaunga plain aquifer in New Zealand (Thirumalaivasan et al, 2003). A study by Neshat et al (2014) estimated groundwater susceptibility to contamination in the Kerman Agricultural Area of Iran by modifying the allocated weights and rates in a modified DRASTIC.

Additionally, in a research using nitrates conducted in Jilin City, northeastern China, a modified DRASTIC was adopted by eliminating the existing criteria (Huan et al., 2012). Modified DRASTIC models have been utilized in a number of additional researches, To evaluate groundwater susceptibility to contamination, refer to Javadi et al (2010), Sener et al (2013), Meng et al (2007), Fritch et al (2000), and Wang et al (2012). According to a number of researches, groundwater nitrate pollution could be identified using the results of the DRASTIC model (Javadi et al., 2010; Panda, 2008; Remesan and Huan et al., 2012). In NE Korinthia, Greece, a study by Antonakos and Lambrakis (2007) concentrated on the creation and evaluation of three hybrid approaches 56 for the evaluation of aquifer susceptibility to nitrates based on DRASTIC modelling. Analogous research was also conducted by Javadi et al (2010), Al-Adamat et al (2003), and Neshat et al (2014), which shown that groundwater susceptibility may be accurately predicted by utilizing nitrate in modified DRASTIC models.

1.4 Research Problems

- Evaluate the quality and availability of data for modeling.
- Determine the critical elements influencing the susceptibility of groundwater.
- Analyze how susceptibility has changed throughout time.
- Examine how vulnerability varies throughout places.
- Check the model's accuracy with actual data.
- Think about how vulnerability may vary due to climate change.
- Examine the effects on groundwater management policies.
- Examine strategies for involving local populations in groundwater protection.

1.5 Research Goal

This research aims to: (i) evaluate groundwater contamination vulnerability using US EPA-established DRASTIC parameters; and (ii) enhance the vulnerability model by incorporating groundwater nitrate concentrations and land cover data from sophisticated GIS analysis.

Chapter 2

Geography and Geology of the Study Area

2.1 Study Area

The Islamic Republic of Pakistan's capital, Islamabad, is situated between latitudes 33.2801200 N and longitude 72.4803600 E. The population was 40,000 in 1950, 110,000 in 1995, 678,000 in 2005, 1.095 million in 2018, and is predicted to reach 1.67 million by 2030, according to the United Nations World Urbanization Prospects (2018). These numbers relate to the urban agglomeration of Islamabad, which often includes both the city's population and neighboring suburban areas. Constructed in the late 1950s by urban planner Constantinos A. Doxiadis and associates, the city growth is swift. The city is a "unique" example of a significant new metropolis that is "planned for the future and built for the present," and it fully adheres to long-term planning (Frantzeskakis et al., 2009). It is between 400 and 650 meters above sea level., and its area is around 906 km^3. Zones I through V, which are different residential sectors, make up the study area. The seasons are as follows: winter (November to February), spring (March to April), summer (May to June), monsoon (July to August), and fall (September to October). Humid subtropical weather prevails (Naeem et al., 2018). June is the hottest in Islamabad, with a record high temperature of 46.5°C established in 2005. In 2010, there were four consecutive days with a high of over 40°C. In contrast, statistics for 2018's summer days showed temperatures between 30 and 44°C. Eleven days between 1993 and 2012 saw temperatures reach above 44°C. The geology is composed of limestone, tertiary sandstone, and a few alluvial deposits (Butt et al., 2015). Figure 2.1 Geographical Indicates the study area.

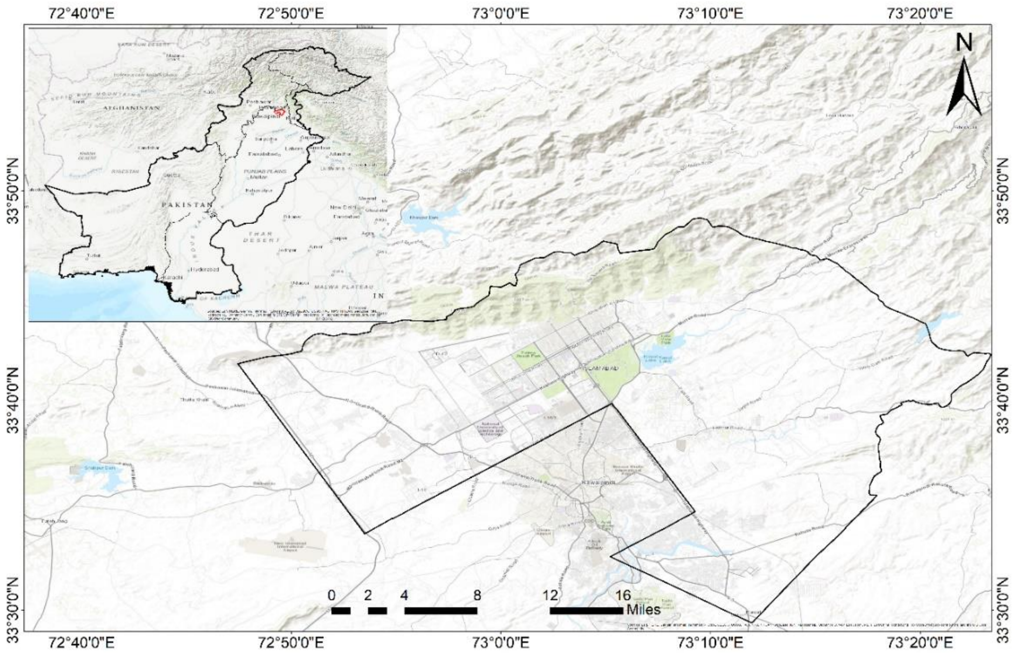

Figure 2.1 Geographical Location of Islamabad

2.2 Tectonics and Geology of study area

The geological background of Islamabad is complex and diverse, with a variety of rock formations and geological features. The city is located in the Pothohar Plateau, a region characterized by folded and faulted rocks. The most prominent geological feature in Islamabad is the Margala Hills, a range of mountains that run along the northern edge of the city. The Margala Hills are composed of sedimentary rocks that were deposited in a marine environment millions of years ago (Afzal et al., 2023; Sheikh et al., 2008; Saleema et al., 2023).

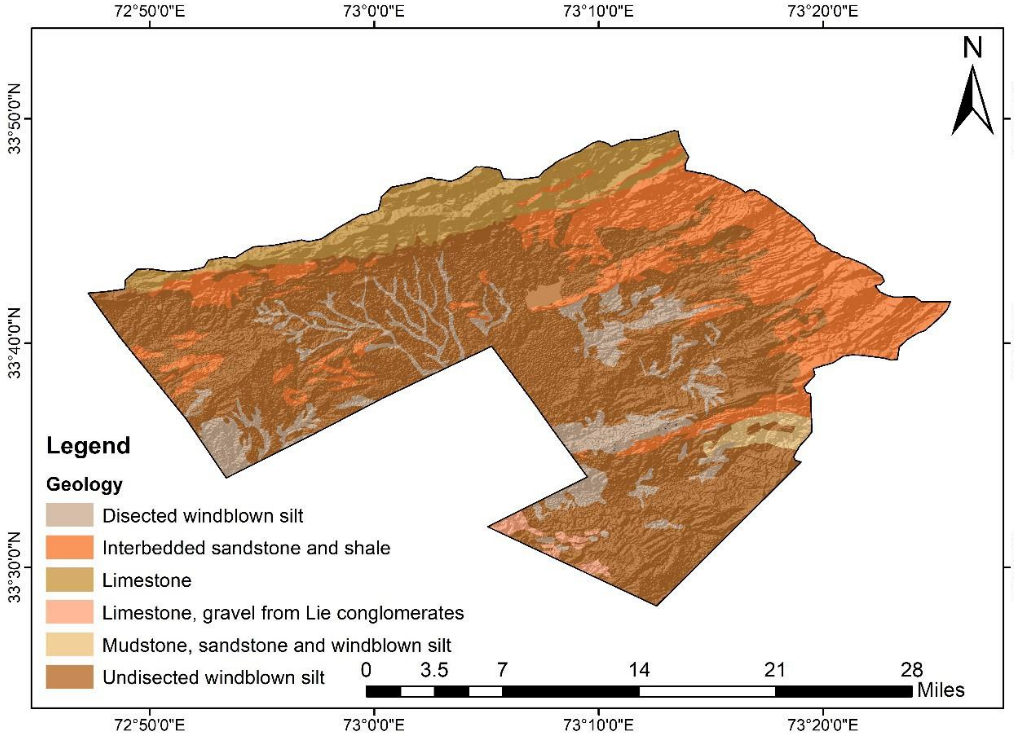

Figure 2.2 Surface Geology of Islamabad Digitized after Khan et al (2021)

2.3 Paleography of Indian and Eurasians plate throughout geological scale.

India remained an island continent after Gondwana broke apart, but it reconnected with Africa biotically in the Late Cretaceous when it collided with the Kohistan-Ladakh Arc (~ 85 Ma) along the Indus Suture (Chatterjee et al., 2013). India rapidly moved northward as an island continent bearing Gondwana biota between 67 and 50 million years following the Deccan eruption; this mobility abruptly decreased to 5 cm/year with its collision with Asia in the Early Eocene (~ 50 Ma) (Chatterjee et al., 2013). Soon after the collision, a northern corridor that allowed for the interchange of fauna was created between Asia and India (Chatterjee et al., 2013). Mixed Gondwana and Eurasian elements found in the fossil record preserved in various Indian continental Eocene formations are indicative of this (Chatterjee et al., 2013).

The Indo-Eurasian collision has had a significant impact on the geology of the Eastern Himalayas. The collision created the Himalayas and Tibetan Plateau, and it is still causing earthquakes and uplift of the mountains. The collision did not have a direct impact on the formation of the Abor Volcanics, but it may have indirectly affected them by causing uplift of the Himalayas (Ali et al., 2012; Bhattacharya and Yatheesh, 2015; Searle, 2019)

Chapter 3

Research Methodology

3.1 Materials and Methods

The study assesses Islamabad's groundwater contamination, and in order to address this problem, high-vulnerability areas are located and assessed utilizing the DRASTIC model based on GIS. The DRASTIC model based on GIS was created in 1985 by the US EPA and NAWWA, as was indicated in the preceding chapter (Aller et al., 1987). Groundwater management has seen a notable increase in the use of the GIS-based DRASTIC approach because of its minimal indexing classification and dependence on well-established information. The primary objective of the DRASTIC Approach is to create a geographical representation of areas with changing susceptibility to contaminations and use that map for different groundwater control tasks. The term "DRASTIC" is used for this purpose because, as stated by Aller et al (1987), it has seven criteria, comprising topographical and hydrological features.

The methodology had three stages: (1) Gathering Input Data; (2) Creating the Vulnerability Model; and (3) Calibration of the Model and Creation of the Final Vulnerability Map. A detailed study plan is shown by the flowchart (Fig. 3.1).

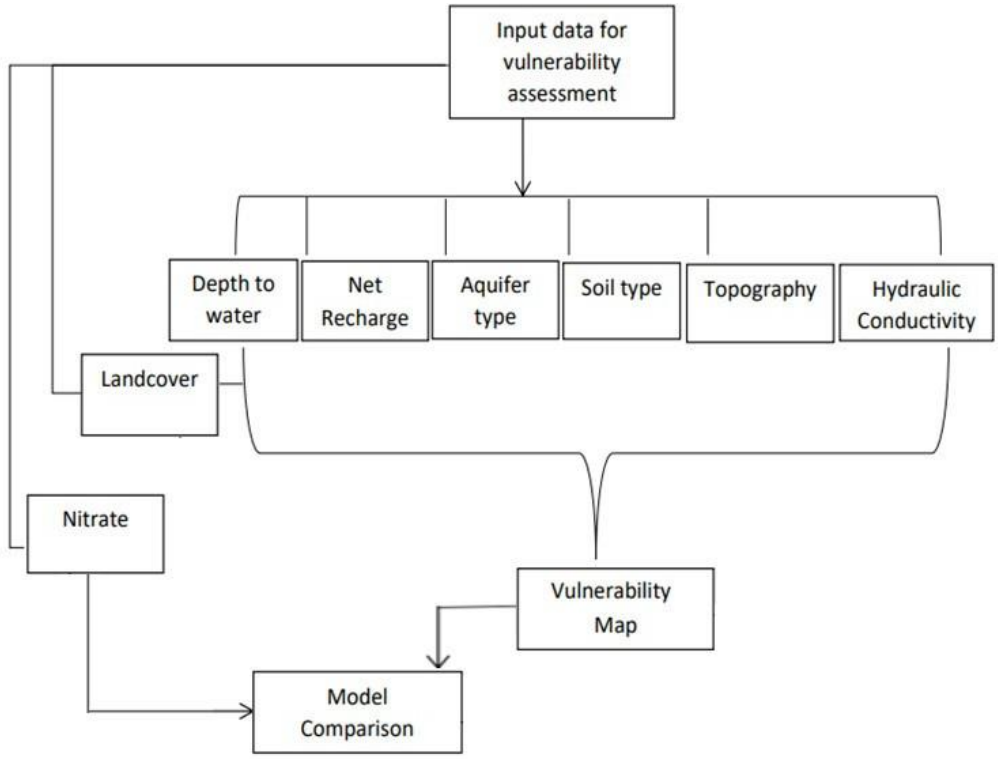

Figure 3.1 A Flow chart of the methodology for groundwater vulnerability assessment using DRASTIC Model in GIS

Because the DRASTIC model can accurately and operationally symbolize any possible parameter associated with subsurface water susceptibility, it was chosen with great care. As was previously mentioned, there are several models and techniques for determining the susceptibility of ground water. The index produced with the use of any auxiliary tool, such LIWIS or GIS. A further rationale for selecting the DRASTIC approach is its ability to provide information.

There are four main components to the DRASTIC model.

a. Weight
b. Ranges
c. Ratings
d. Drastic Index

3.2 Weight

A precise weight has been allocated to each component in depending on its significance, relative influence, and role in the transfer of contaminants to subterranean water reserves. According to Babiker et al (2005), The weight might have comparable values between 1 and 5 suggesting elements that have high values and just little contribute to subsurface water susceptibility indicating important influences. For example, water depth (component D) been given the elevated value of "20" since deepness influences subsurface sensitivity to water in a considerable way. Pollution would be less probable if the water's "D" depth was greater, despite the fact that it would be more likely if the water were close to the surface and shallow. Given its small effect on subsurface water susceptibility, weight "20" has been applied to the topographical parameter, which influences slope. In one way or another, slope will manage the overflow. Because excess water might linger for extended periods of time, softer slopes would increase the likelihood of underground water pollution.

The weight will be decided by applying the Delphi system, which considered the observations and opinions of numerous specialists according to their competence and capacity (Aller et al., 1987).

3.3 Ranges

Every factor is placed into one of several media categories, or "Ranges." These particular classes or ranges have been established to facilitate the development of susceptibility protocols in regions characterized by fluctuating lithology, rock types, and hydrogeological characteristics. Separate class calculations have been done in conjunction with other classes to make clear each class's relative significance in relation to the risk of subsurface water pollution.

3.4 Ratings

Each element's range has been assigned an amount that shows how important it is concerning the possibility of subsurface water pollution (Aller et al., 1987). The process of grouping specific rocks based on a range that depicts their respective contributions under groundwater contamination is referred to as "rating." The assigned Rating has a range of 1 to 10.

In comparison to a higher-rated range that suggests a particular media kind has more possibility, one hydrogeological component may have less potential if it is rated lower in a range to contaminate subsurface water. For example, Underlying contamination is more likely to be present in shallow water, therefore Depths up to 25 metres have been given a rating of 10. Deeper depths, on the other hand, have a rating of up to 2, indicating their significant vulnerability to contamination.

3.5 Drastic Index

Using the weights, ranges, and ratings, the DRASRIC Index (DI) can be computed that were once assigned to every hydrological parameter with the help of the straightforward linear equation given below.

$$DI = Dr*Dw+Rr*Rw+Ar*Sw+Tr*Tw+Ir*Iw+Cr*Cw \quad \text{(Eq. 1)}$$

Where;

D R A S T I and C are the DRASTIC parameter explained in table 1.1

(r) represents Rating and (w) represents weights

The calculation of the DRASTIC Index using the provided equation indicates the relative sensitivity of subsurface water to pollution. Areas with higher susceptibility are easier to identify and are used in determining the DRASTIC Index (DI). A higher susceptibility index indicates greater vulnerability of the groundwater aquifer to pollution, while a lower DI score suggests a less sensitive area. It's important to note that a low susceptibility index in a zone does not guarantee absence of subsurface water contamination; such areas should not be considered unsusceptible. The Infect Less Index indicates zones with comparatively lower susceptibility to pollution (Almasari, 2008). Depending on the purpose and the susceptibility range from the research area, the DI DRASTIC index can be classified into various ranges or classes, such as low, moderate, high, and extremely or very high.

3.6 Data collection

In order to perform the susceptibility calculation approach utilizing the DRASTIC method, a large quantity of data management is required to prepare the input data for the DRASTIC factor participants. Every DRASTIC technique parameter has its data collected, with different kinds of required data obtained from public and private sources. As part of the study, field inspections were also carried out to confirm specific details, including water depth, geographical locations, and water well placement. Two categories of data are created from the acquired data: primary and secondary.

3.6.1 Primary data

In addition to well logs, strata charts, lowering charts, and stratum charts collected from the CDA and FAO Soils, information was gathered from several field studies conducted in the research region.

3.6.2 Secondary data

The secondary data came from a wide range of official and unofficial government agency and organization archives, as well as a large number of research papers, publications, census data, and public records. The table below shows the many types of information and data pertaining to various hydrological factors. Table 3.1 contains the source references for the data.

Table 3.1 Reference to the data's source

Number	Layer	Data Format	Source
1	Depth to Water Table	Field Data, Excel Sheet	Field Survey
2	Net Recharge	Raster Layers	Literature, USGS, GSP
3	Aquifer Media	Lithological Logs, Excel Sheets	CDA, Field Survey
4	Soil Media	Raster Layer	FAO Soil
5	Topography	DEM	USGS
6	Impact of Vadose Zone	Lithological Logs, Excel Sheets	CDA, Field Survey
7	Hydraulic Conductivity	Excel Sheet	Literature

3.7 Desk research and expert evaluations

Delphi system forms the foundation of the GIS-based DRASTIC model, specialists in the area, such as hydrologists and hydrogeologists, were consulted for their insights and explanations regarding the ranges of hydrological parameters.

3.8 Field surveys

A field survey was conducted in Islamabad to determine the various locations of boreholes and the water depth in each. Finding water wells using GPS data and obtaining their geographic coordinates was the field's main goal. During the field survey, 38 water samples were also collected in order to test for the nitrate parameter.

3.9 Literature survey

The study subject and its foundations were investigated through a comprehensive evaluation of the literature, which included a review of numerous research papers, reports, draughts, and official and unofficial statistical data. A review of the literature was done in order to.

I. Put together the fundamental structure of the GIS-based DRASTIC model.
II. Acknowledge the three types, functions, consequences, and applications of the DRASTIC model.
III. Recognize and appreciate how complicated the field of study is.
IV. Assemble information and materials to depict the research area.
V. Gather data about all the different aspects of the research process.

3.10 Software and tool

Geographic information technologies were used for modelling the susceptibility index's spatial distribution and dissemination for this study. GIS programs, such as Google Earth and ArcGIS 10.8, were used to examine and display the collected data. Geographic information systems (GIS) were used in this work to collect data and then translate it into a thematic map layer, even though the DRASTIC index can also be derived manually. Microsoft Excel was utilized for the tabulation of all the collected data. GPS was utilized to pinpoint the precise position of water wells during field visits. Resources included Google Earth, Google Maps, and tourist and topographic maps acquired from an exploration of Pakistan.

3.11 Generating Layers for DRASTIC Factors

The collected data was used to create thematic map overlays of the DRASTIC variables. The process of creating layers involves analyzing the data that is currently accessible and factoring in raster format layers. GIS is the tool that is used to express information in raster format. Many interpolation approaches are available to offer spatially scattered data concerning key hydrogeological parameters in GIS.

3.12 Input Data Collection

The study employed a number of DRASTIC factors, including soil media, aquifer media, depth to water, net recharge, topography (percent slope), hydraulic conductivity, and the effect of the vadose zone. The composition of the land and the concentration of nitrate in each drinking water well are other factors that are taken into consideration.

3.12.1 Depth to water table (D)

Depth of the water is one of the most important parameters in the DRASTIC technique, this establishes the minimum distance a pollutant must travel from the surface to the groundwater table (Aller et al., 1987). Put another way, it's the vertical distance in the aquifer between the top of the saturated zone and the water table. Contour maps of the topography and groundwater level could be used to determine it. Depth to water would be computed by deducting elevations from groundwater level. Generally speaking, the likelihood of contamination declines as D increases since a deeper water table suggests a lower likelihood of contamination (Han et al., 2016).

3.12.2 Net Recharge (R)

Pollutants are transferred to an aquifer mostly through net groundwater recharge. We refer to the total amount of water that reaches the water table as net recharge. The research area's evapotranspiration, absorption wells, irrigation return flow, and rainfall infiltration can all be used to estimate net recharge. The susceptibility to contamination increases with recharging (Aller et al., 1987). Rainfall or river leaks could be the primary source of recharging. Isotope studies could potentially be used to generate the groundwater recharge map (Brown et al., 1999).

3.12.3 Aquifer media (A)

Aquifer is a rock formation that yields enough water for human consumption, according to Aller (1987). Consolidated and unconsolidated rocks that act as aquifers, such as sand, gravel, or limestone, are referred to as aquifer media. This parameter is required to control the length, direction, and flow of pollutants along the path. greater vulnerability to pollution can generally be attributed to sediment larger in size, increased permeability and decreased capability for attenuation. Geological data could be used to create an aquifer media map.

3.12.4 Soil media (S)

According to Aller et al (1987), The soil medium is a representation of the upper, worn region of the unsaturated zone with strong biological activity. It is the head portion of the vadose zone, and its features are significant for possible pollution, whereas decreasing infiltration will occur as soil depth increases. Pollutant infiltration rates are typically shown via soil maps. The type of clay, its grain size, and its shrinkage potential are some of the important variables that affect the likelihood of soil pollution. Less clay, less possibility for shrinkage, and smaller grains do, in fact, imply a lower level of aquifer vulnerability.

3.12.5 Topography (T)

The slope angle of the surface is referred to as "topography" and it controls how much pollution runs down. The probability that pollutants will either flow off or remain on the ground and penetrate is indicated by this factor. As a result, steep slopes enhance runoff that carries contaminants and decrease the possibility of penetration. Elaish and Hallaq (2012). Topography maps could be produce using the Digital Elevation Model, and GIS tools can determine slope.

3.12.6 Impact of vadose zone (I)

When groundwater is compressed to atmospheric pressure, the region between the top of the ground and the depth of water is referred to as the vadose zone, also called the unsaturated zone (Stephens, 2018). Vertical water movement is necessary for the transport of contaminants in the vadose zone. The properties of the unsaturated zone can be utilized to ascertain the absorption capabilities of the media above the water table (Dahan et al., 2009). A vadose zone map is also created using the lithology and subsurface geology found in drilling logs.

3.12.7 Hydraulic Conductivity (C)

An aquifer's ability to transport contaminants and water is known as hydraulic conductivity (Lobo-Ferreira and associates, 2005). Hydraulic conductivity distribution map is made using lithology and pumping test results. Greater pollutant transfer and spread are indicated by regions with higher hydraulic conductivity (Lu et al., 2021). Additionally, pore gaps and aquifer cracks regulate it. The equation k=T/b can be used to determine an aquifer's hydraulic conductivity, where aquifer's hydraulic conductivity is denoted by k (m/d), T (m2/d) represents transmissivity, and b (m) represents the aquifer's thickness (Gheisari, 2017).

3.13 Overlay Index Analysis

The DRASTIC index can be found manually even though this study used the overlay and index approach. The idea of reinforces the overlay method, integrating a layer of every DRASTIC element. Each component or parameter is assigned a specific weight based on the rating assigned to its features in order to calculate the index (NRC, 1993). Furthermore, a number of statistical tests were performed to assess the rationality of the layer that was produced in this manner. For example, sensitivity analysis and various map removal methods. The stress-free implementation of this kind of strategy has been made possible by online technologies that address the spatial notion of massive informational volumes. The geographic information system and the integrated land and water information system (ILWIS) are two instances. In the ArcGIS software, each hydrogeological parameter's layer overlapped. after each layer was given the appropriate rating and weight. The weight of the relevant thematic layer was multiplied by the ratings assigned to different classes to estimate the parameter "Dr*Dw," where "Dw" denotes the parameter's weight and "Dr" denotes the ratings assigned to certain factors. The weighting and rating of each parameter were looked at, and the corresponding ranges were then added together. Equation 1 was utilized to get the DRASTIC index.

Chapter 4

Results and Discussions

The approach for collecting, organizing, assembling, and compiling data as well as the strategy for applying and utilizing this data in groundwater susceptibility assessment were thoroughly covered in the study's previous chapter. The vulnerability of the shallow subsurface water in Islamabad's central region has been assessed using the DRASTIC model. Every thematic map layer will be thoroughly examined in this chapter.

4.1 Depth to water table (D):

A field survey was done to find out how deep is the water table by collecting the depth measurements from different boreholes in feet along with their coordinates. Later on, using ArcGIS in interpolation method was applied on the obtained data from field and by IDW the water table map was generated. Subsequently, the generated map was transformed into a raster format for additional examination. After that, ranges were created on the water table map's depth, and each class was given a rating between 1 and 10, with 1 representing deeper water tables (lower influence on susceptibility) and 10 signifying shallow water tables, which have the biggest influence on susceptibility. Figure 4.1 shows the depth to water map.

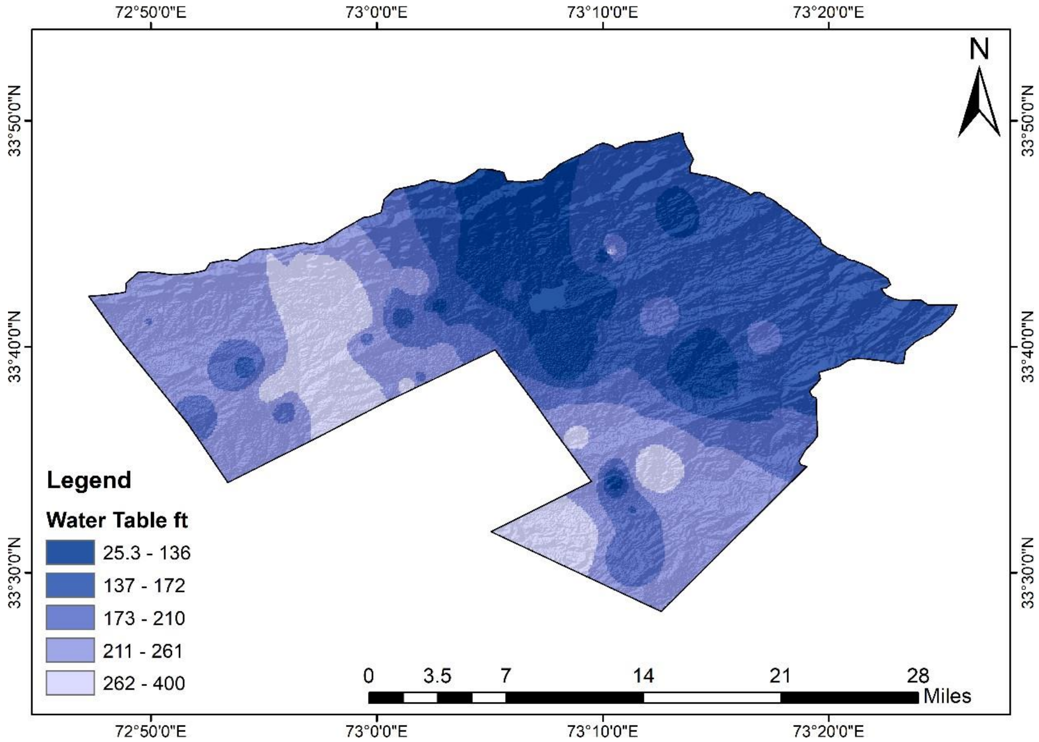

Figure 4.1 Map showing water table of Islamabad

4.2 Net Recharge (R):

The main way that precipitation gets into the ground and reaches the water table on Earth is through percolation. Net recharge is often described as rainfall infiltration, absorption wells, and irrigation return flow (Aller et al., 1987). Because recharging would make it easier for pollutants to go to the water table, aquifers with higher net recharge are more susceptible to contamination. These three thematic layers—soil, rainfall, and topography—were added to ArcGIS in order to calculate the total net recharging in the Islamabad aquifer. Based on the attributes, rates, and weightings assigned to each theme layer, a net recharge map was created. This layer and its rated raster are displayed in the research region in Figure 4.2.

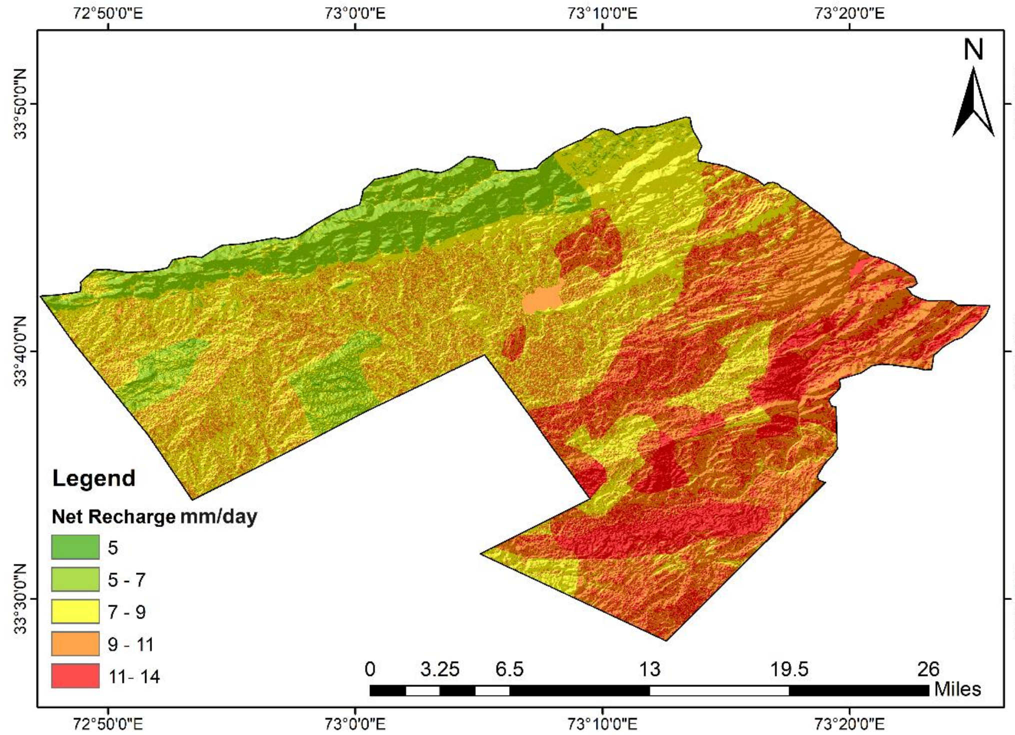

Figure 4.2 Map showing Net Recharge of Islamabad in mm/day

4.3 Aquifer media (A)

Using Lithological logs by CDA and VES data from the literature, the aquifer media layer map was made. The Aquifer media was marked using field data based on accessible data from CDA and the VES study. After that, the Aquifer Media map was created in ArcGIS using the interpolation technique. The aquifer media were rated and given weights according to the kind of rock formation and level of permeability. Higher permeability materials were rated a 10 since they were the most susceptible to contamination. Because of the poor rate of permeability, the least vulnerable aquifer media received the lowest rating of 1. Figure. 4.3 illustrates the various aquifer media types in the county.

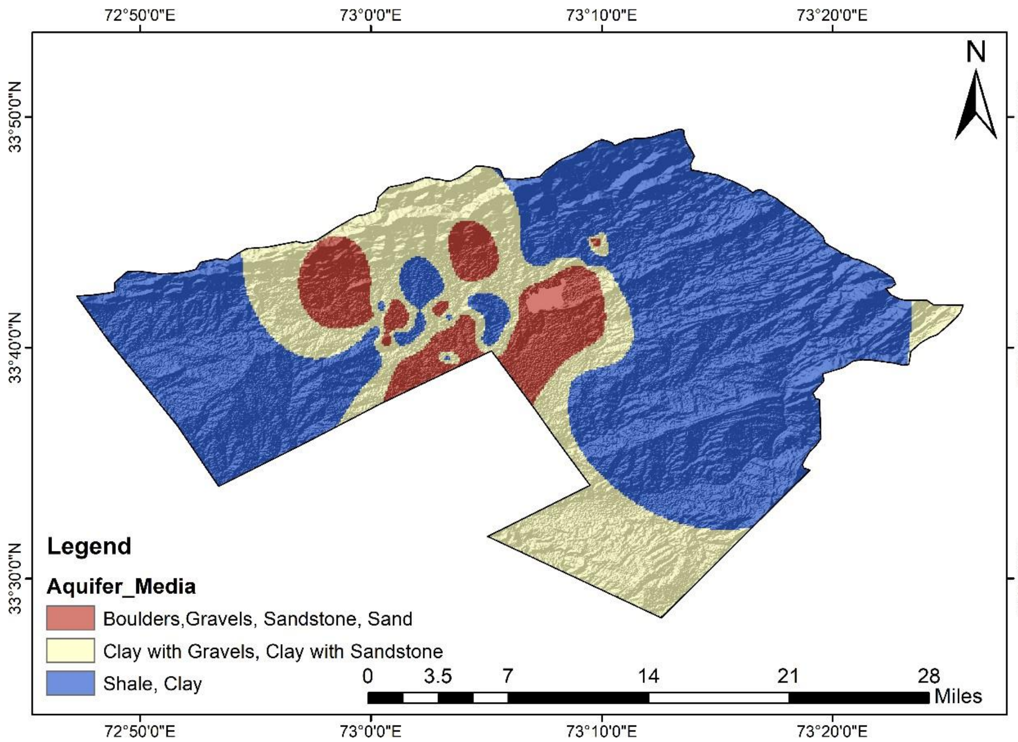

Figure 4.3 Map showing Aquifer Media of Islamabad

4.4 Soil media (S)

Above the vadose zone, the weathered section is called soil, which is usually 1.8 meters or less (Aller et al., 1987). The type of soil dictates how much net recharge may reach the groundwater system. The kind of clay and the soil's particles size actually have the biggest impacts on how polluted the soil might be. Therefore, a reduced chance of pollution is indicated by more clay and smaller grain size (Aller et al., 1987). FAO soil data were used to create the Islamabad soil map. The primary types of soil found in Islamabad are patchy and nearly continuous mountainous land, piedmont and patchy mountainous land, and calcareous silty soil-gullied land complex. Appropriate ratings and Wrights were allocated in ArcGIS according to the characteristics of their water infiltration.

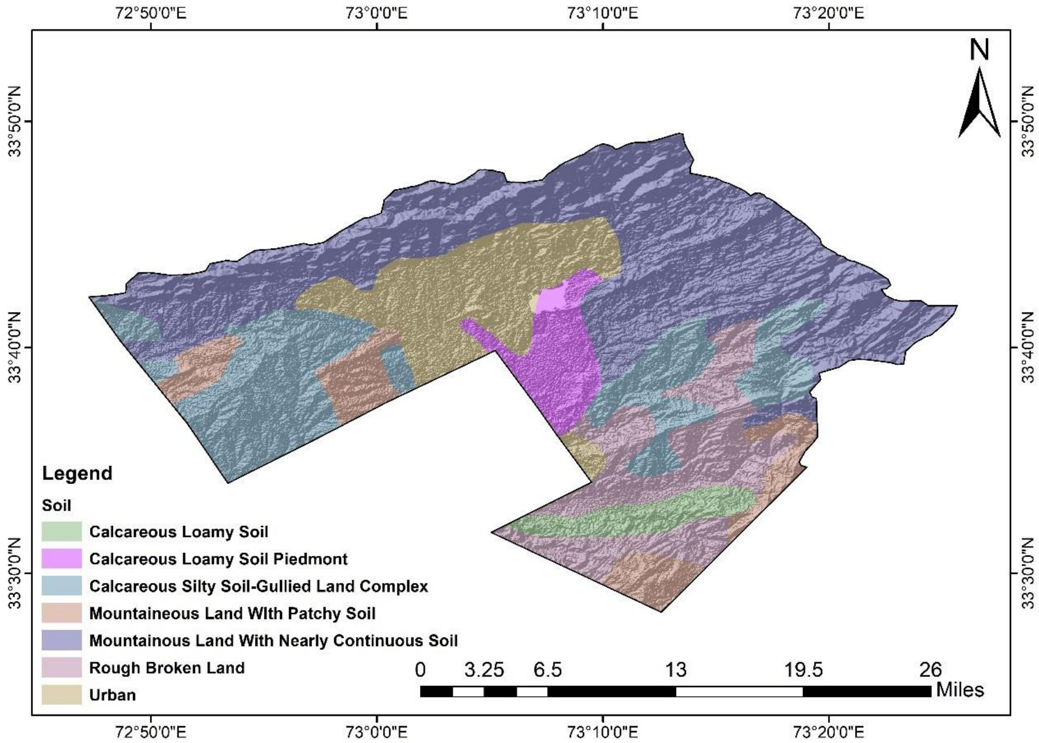

Figure 4.4 Map showing Soil Media of Islamabad

4.5 Topography (T)

According to Aller et al (1987), topography describes the slope of the ground, it assesses whether a contaminant will flow off or remain on the surface and penetrate. Topographic surfaces that are steeper are less susceptible to pollution. The Digital Elevation Model provided the terrain, and ArcGIS's Spatial Analyst capabilities were used to calculate the slope. Subsequently, the acquired slope map was split into five classes, the majority of which were located in regions with slopes between 0 and 6.1 degrees, which makes sense given that the area is primarily made up of agricultural areas. Degrees 0 to 6.11, 6.1 to 14.5, 14.6 to 25.2, and 25.3 to 64.8 are the classes that are offered. Figure 4.5 displays the topography of Islamabad.

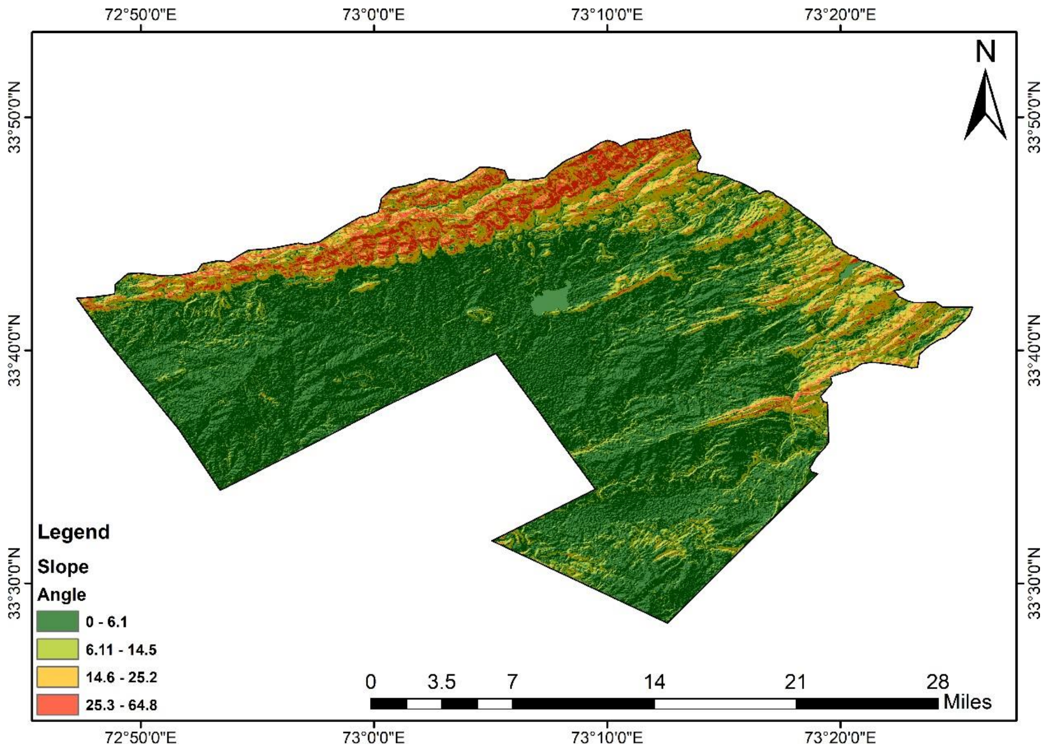

Figure 4.5 Map showing Slope Degree of Islamabad

4.6 Impact of vadose zone (I)

The term "vadose zone" refers to the unsaturated area above the water table (Aller et al., 1987). The Capital Developmental Authorities well logs were classified as the impact of the vadose zone of Islamabad and a literature research that included a field survey to mark the media within the zone. The vadose zone map was created by interpolating the available data. The area's most significant features were Clay and Shale. As a result, three classes were created to represent the influence of the vadose zone, and they are displayed in Figure 4.6 with an impact of vadose zone rate (Ir) of 5.

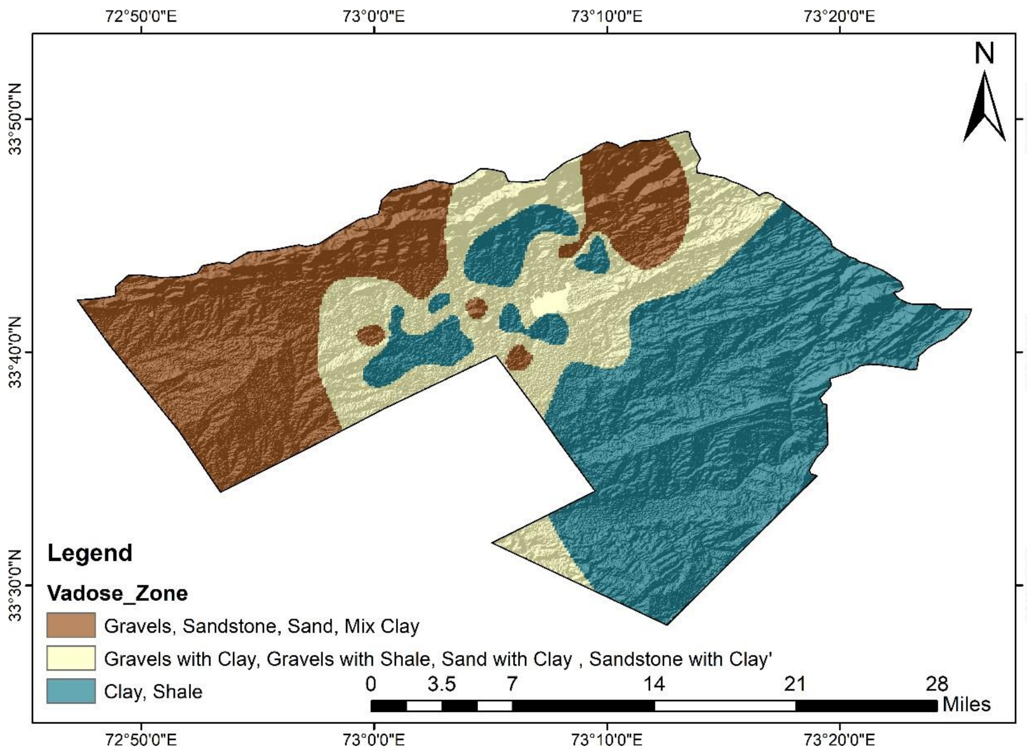

Figure 4.6 Map showing Vadose Zone Media of Islamabad

4.7 Hydraulic Conductivity (C)

Due to lack of having proper equipment's an indirect method was used to find the Hydraulic Conductivity.

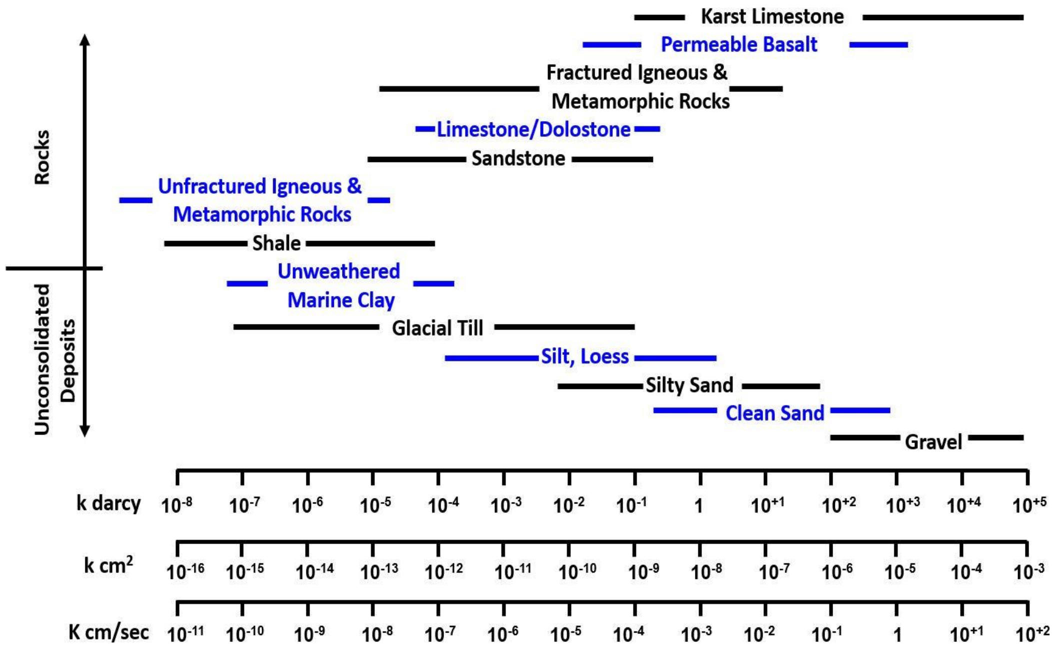

Figure 4.7 Ranges of the values of hydraulic conductivity (K) and intrinsic permeability (k).

A helpful chart of unconsolidated material's inherent permeability (k) and hydraulic conductivity (K), as well as that of sedimentary rocks, igneous and metamorphic rocks, and unconsolidated material, is provided by Freeze and Cherry (1979). Figure 4.7 illustrates this table. The chart is meant to be easier to read by using alternate colors. To convert, use 1.02 × 10-5 cm2 and 1.04 × 103 darcy as the values for 1 cm/s (Freeze and Cherry, 1979). The range of values for intrinsic permeability and hydraulic conductivity in three different systems of units is shown in this picture. Hydraulic conductivity varies across a broad range, according to the statistics. Few other physical parameters can have values that vary by more than 13 orders of magnitude. This large range of numbers practically indicates the utility of knowing the hydraulic conductivity order of magnitude. On the other hand, it suggests that a hydraulic conductivity value reported to the third decimal place is probably not very significant.

In the study region, the hydraulic conductivity from the same aquifer media was identified and classified into 5 classes as Very High, High, Moderate, Low, and Very Low based on the table by Freeze and Cherry. Very High indicates Boulders, the High is for Gravel, Sand, Sandstone and Sand + Gravel, Moderate shows Clay with Gravel and Sandstone, Low point outs Shale and Very Low focuses on Clay.

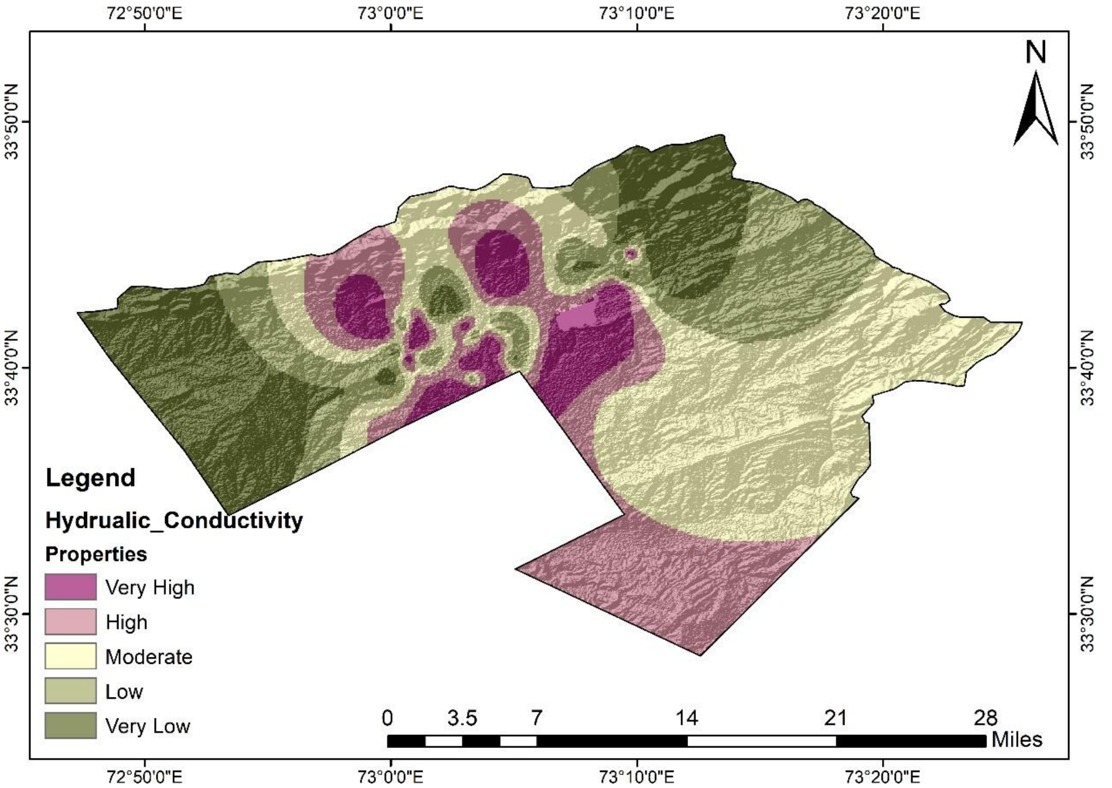

Figure 4.8 Map showing Hydraulic Conductivity Ranges of Islamabad

4.8 Land cover (LC)

To achieve this, we turned to satellite imagery, specifically utilizing data from the Sentinel II satellite. This advanced Earth observation satellite provides high-resolution and multispectral data, allowing us to discern different land cover types with precision. By leveraging this satellite imagery, we were able to develop a comprehensive land cover map for Islamabad. Most of the area in Islamabad is covered by Urban land and the minimum is covered by water bodies.

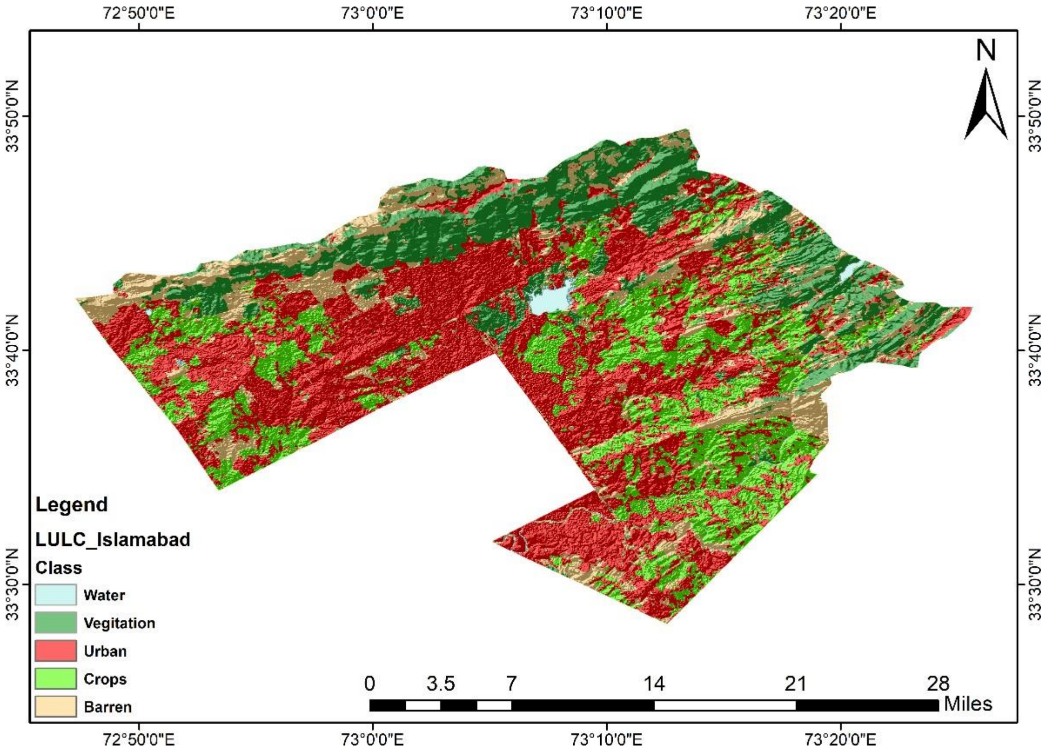

Figure 4.9 Map showing Land Use and Land Cover classification of Islamabad

After creating all the thematic layers and assigning different weights and rating (Table 4.1) to each, Analysis using Weighted Sum was done in ArcGIS for the production of DRASTIC Vulnerability Map.

Using Equation (1), The final DRASTIC index map was created using ArcGIS and a weighted sum analysis. Figure. 4.10 displays the map of the DRASTIC index. Water samples were gathered, and their nitrate content was measured in the laboratory. The nitrate's geographical distribution was then mapped using interpolation, and this map was then utilized in order to adjust the DRASTIC index map. Figure. 4.11 illustrates geographical distribution of nitrate concentration. In this study, data from multiple sources was compiled, presented, interpolated, and analyzed using ESRI's ArcGIS 10.8. Every map in ESRI's ArcGIS was projected using the WGS 1984 projection method.

Table 4.1 The Weight and Rating assigned of each influencing DRASTIC Parameters

Parameter	Ranges	Rating	Weight
Depth to water table (ft)	25.3 - 136	10	20
	137 - 172	7	
	173 - 210	5	
	211 - 261	3	
	262 - 400	1	
Net Recharge	Very High	10	15
	High	8	
	Moderately	6	
	Low	3	
	Very Low	1	
Aquifer Media	Boulders, Gravels, Sandstone, Sand	10	5
	Clay with Gravels, Clay with Sandstone	6	
	Shale, Clay	1	
Soil	Calcareous Loamy Soil	4	10
	Calcareous Loamy Soil Piedmont	6	
	Calcareous Silty Soil-Gullied Land Complex	8	
	Mountainous Land with Patchy Soil	6	
	Mountainous Land with Nearly Continuous Soil	4	
	Rough Broken Land	8	
	Urban	10	
Topography	0 - 6.1	10	10
	6.11 - 14.5	5	
	14.6 - 25.2	3	
	25.3 - 64.8	1	
Vadose Zone	Gravels, Sandstone, Sand, Mix Clay	10	5
	Gravels with Clay, Gravels with Shale, Sand with Clay, Sandstone with Clay'	5	
	Clay, Shale	1	
Hydraulic Conductivity	Very High	10	5
	High	8	
	Moderately	6	
	Low	3	
	Very Low	1	
Land Use and Land Cover	Water	10	20
	Crops	8	
	Vegetation	7	
	Barren	4	
	Urban	2	

4.9 Drastic-based intrinsic vulnerability assessment

Depending on the specifics of each research goal and study region, the GIS-based DRASTIC model was often adjusted in previous studies by adding or deleting one or more aquifer or environmental elements. The two primary modifications are the adding of new parameters and the updating of ratings.

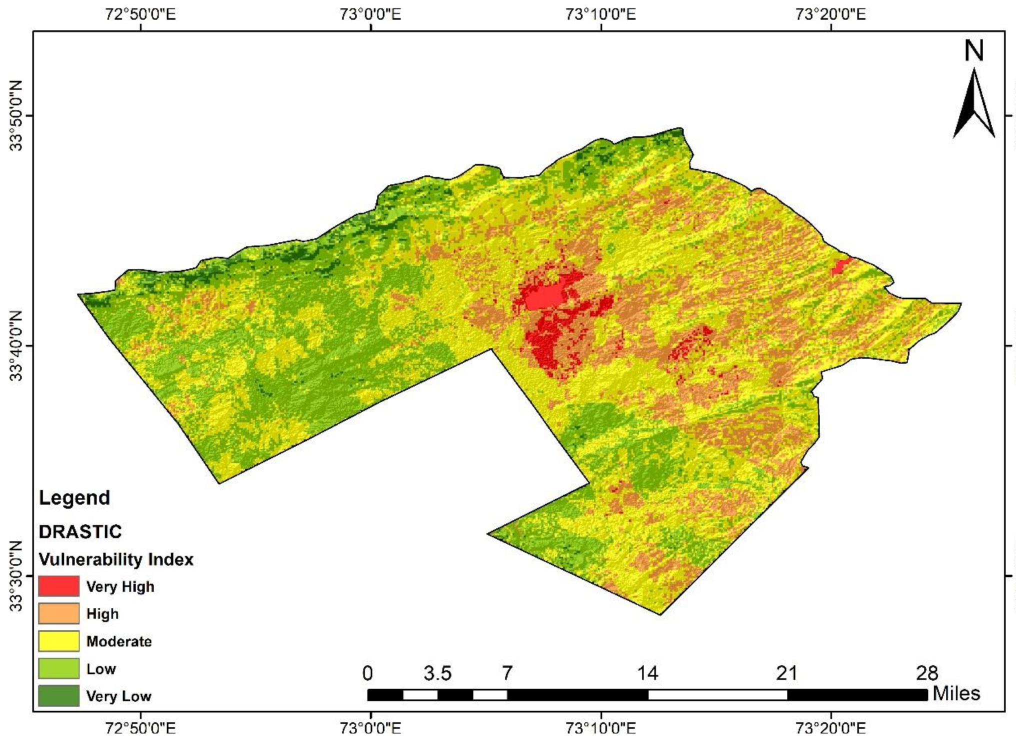

Figure 4.10 DRASTIC Vulnerability Index map of the Islamabad

Five susceptibility classes—Very High, High, Moderate, Low, and Very Low— were identified in this investigation. Following the creation of the calibration map, the consequences of human activity were evaluated using the nitrate concentration map and provide a more realistic image of the susceptibility to contamination. The values of the DRASTIC index varied from 275 to 900, lower DRASTIC index mean low chance of contamination.

Five classes comprise the values of the DRASTIC index i.e., Very Low Vulnerable Zone (275 - 473.5) Low Vulnerable Zone (473.6 - 549.5) Moderate Vulnerable Zone (549.6 - 620.6), Highly Vulnerable Zone (620.7 - 701.5), Very Highly Vulnerable Zone (701.6 - 900). Several other methods are used to categorize DRASTIC index values, e.g. Histogram valleys-based categorization (Kumar et al., 2020). Table 4.2 displays the statistics of the DRASTIC index values.

Table 4.2 Statistics of the DRASTIC Index

Class	**DRASTIC Index**	**Area km^2**	**Area %**	**Color**
Very High	775 - 900	26	2	
High	650 - 775	221	21	
Moderate	525 - 650	500	47	
Low	400 - 525	306	28	
Very Low	275 - 400	22	2	

The range of water depth in the research area was determined by using 38 wells' depth to water table data. The water depth in the vicinity of Rawal Lake was shallow, ranging from 25 to 136 feet, while other locations, such as the E-11 regions, had deeper water, with depths ranging from 262 to 400 feet. The area with little water depth had a high rating of 10, while the deeper water table received a low rating of 1. Figure 4.1 displays the water table's depth for each location.

A net recharging map was produced by computing the soil, rainfall, and slope data to ascertain the net recharge data. In the Rawat and Southern East regions, the net recharge was higher (11–14 mm/day) than in the Margalla Hills regions, where it was lower (5 mm/day). High net recharging locations received high ratings (10), whereas locations with little net recharge received low ratings

(1). In Figure 4.2, the net recharge map is indicated. Three classifications make up the aquifer media in the research area: i) Boulders, Gravels, Sandstone, Sand; ii) Clay with Gravels, Clay with Sandstone; and iii) Shale, Clay. Figure. 4.3 displays the map of the aquifer medium. Four kinds of soil cover were identified in Islamabad. where practically continuous soil covers the majority of the land. Figure. 4.4 displays the soil media map. The topography layer displays degrees ranging from 0 to 64.8, much of the research area falling within between low and 6.1 degrees, which denotes a level area. In Figure 4.5, the topography map is displayed.

Shale and clay were rated low (1) in the vadose zone layer, while gravel, sandstone, sand, and mix clay had a high grade of 10. Figure. 4.6 illustrates how the vadose zone map has an influence. The hydraulic conductivity map was created using an indirect method (Freeze and Cherry, 1979) due to a lack of resources. Extremely low hydraulic conductivity locations received a low grade (1), while extremely high hydraulic conductivity areas received a high rating (10). A map of hydraulic conductivity is displayed in Figure. 4.8. The land use and land cover map was used to relate human activity on the DRASTIC index. For example, crops received an 8 on the land use and land cover map, whereas water received a 10 on the same map. In Figure. 4.9, the land use and land cover map is highlighted.

4.10 Nitrate data

Islamabad is mostly covered by urban areas. Nitrate contamination in urban areas is often associated with multiple sources, including sewage, septic systems, industrial discharges, and fertilizers. In the absence of extensive agricultural lands in Islamabad, the primary sources of nitrate are likely to be urban-centric activities. Wastewater and sewage from households and industries can contribute to elevated nitrate levels in groundwater. Additionally, the use of nitrogen-based fertilizers in urban gardens and green spaces may further impact nitrate concentrations.

To find the nitrate concentration in Islamabad a field survey was done for water chemistry of Islamabad where samples were collected from different areas of Islamabad along with coordinates and then those samples were analyzed in the

Environmental Sciences Lab in Bahria University Islamabad and after the result with the help of interpolation in ArcGIS a nitrate index map was generated for the display and the results of were used for the regression analysis of DRASTIC modeling with Nitrate concentration.

4.11 Calibration with nitrate concentration

A map of nitrate concentration was produced from the field data using ArcGIS to calibrate the DRASTIC vulnerability map. Nitrate has no source in groundwater. So, if there is nitrate in the ground water then it indicates contamination outside sources. 38 samples were collected from different areas of Islamabad and were analyzed for the nitrate concentration (Fig. 4.11).

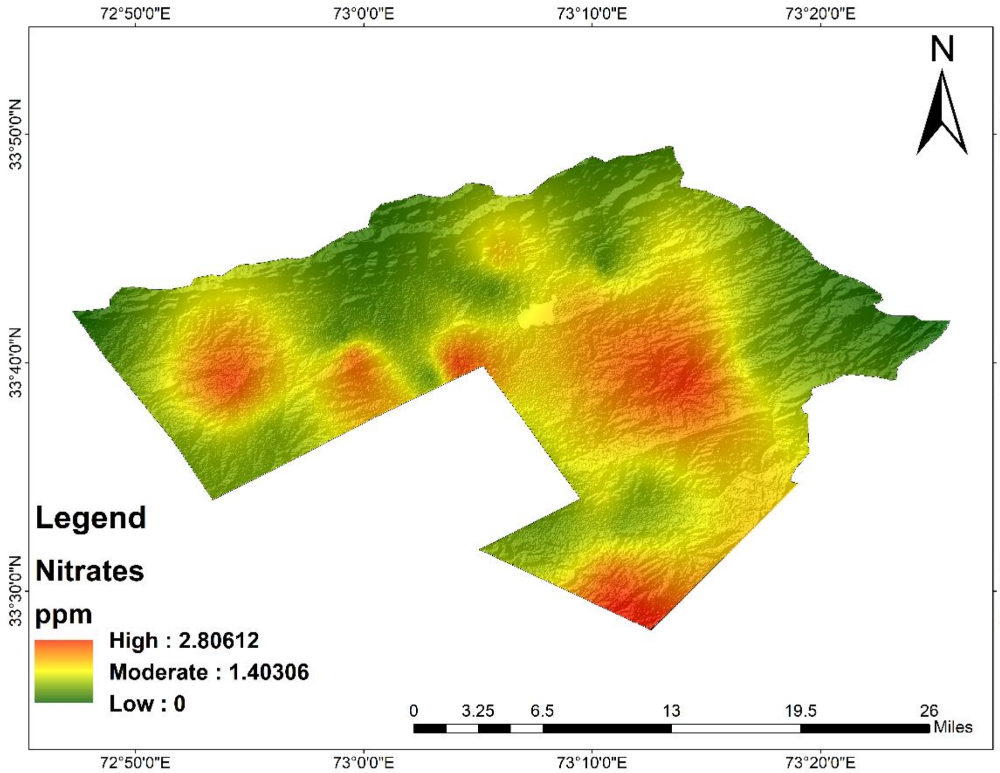

Figure 4.11 Map of Nitrate Concentration in Islamabad

The reported average nitrate in Islamabad was 0.72 parts per million. In contrast, the Pakistan Standard Quality Control Authority (PSQCA) and the National Standard for Drinking Water Quality (NSDWQ) have established a permitted maximum of 10. The observed concentration of nitrate ranged from 0 ppm to 2.41 ppm at its greatest point. There was virtually little correlation between the nitrate concentration map and the DRASTIC index map (Fig. 4.12) but the nitrate was relatively higher in the areas with higher DRASTIC index .

Maqsoom et al (2020) validate their model using nitrate concentration. Their study established three classes of nitrate concentration to be used in calibrating the DI risk map, which was also divided into three classes. Chromium concentrations were utilized by Rajput et al (2020) in order to adjust their DI map. Nitrate concentrations are used by Kumar and Pramod Krishna (2019) to validate their model. For this reason, Nitrate concentration was divided into five grades.

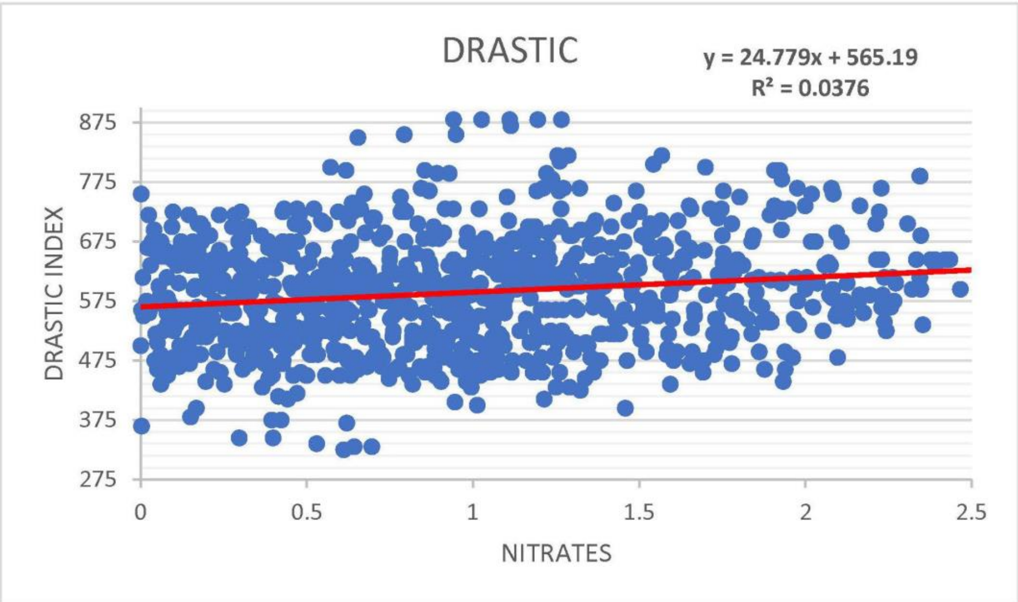

Figure 4.12 Regression Analysis of DRASTIC Index and Nitrate Concentration

4.12 Implications of the DRASTIC index map

The primary regulating elements which are indicated by the DRASTIC index map are the water table's depth, slope, surface water bodies' accessibility, and net recharge (Fig. 4.1, 4.2, 4.5 and 4.9). These variables fluctuate between the moderate index zones' highs and lows. Because they are assigned higher indices and serve as a valuable source of recharge for groundwater, surface water bodies require careful handling when it comes to the disposal of waste and effluents, as is customary in many locations.

The most vulnerable discoveries were made in the Rawal lake area and the NARC (National Agriculture Research Center) area, the main reason can be the exposure of surface water to contaminations and the fertilizers and other chemicals which are used in the researches in NARC. The nitrate results are also relatively higher in this area (Fig. 4.11). Due to having the low degree slope the water accumulates in this area carrying contaminations alongside. This the reason behind high vulnerability index in this area. To sum up and suggest, the first task towards which should be handled in very high vulnerability areas should be the treatment of the stream from contaminations which are accumulating into the Rawal lake and the use of proper chemical which are not harmful for ground water in NARC. Most of the people use streams as dumping sites. A proper dumping sites should be use for wastes.

Chapter 5

Insights

5.1 Conclusions

This study assesses Islamabad, Pakistan's pollution vulnerability using the DRASTIC model, which is based on geographic information systems. In the scope of UN Sustainable Development Goal No. 6, which is clean water and sanitation, one of the research's most significant objectives was to give the relevant authorities a foundation for future planning and mitigation measures. The GIS-based DRASTIC model, which was built utilizing pre-existing data in the form of themed map layers, was used to visualize the hazard to groundwater. A region's sensitivity to pollution is determined by a combination of sources of pollution, hydrogeological conditions, and human activity. But in this instance, the surface water influence and the water table's depth had the biggest effects on the index's calculation. The area was categorized into 5 classes after all the calculations, each zone shows different contamination level in the study area. Among the zones are one of extremely low susceptibility, spanning 22 km^2 and with a DRASTIC index between 275 and 400. 306 km^2 were covered by the low vulnerability zone index, which varied from 400 to 525. The intermediate vulnerability zone index (525 - 650) covered the greatest area, 500 km^2. A 221 km^2 area was covered by the high vulnerability index (650–775) and a 26 km2 area by the extremely high vulnerability zone index (775–900). The equal intervals approach was used to classify these data. A total of 38 water samples were gathered, and their nitrate concentration was measured in the laboratory for calibration. The most dominant zone was the moderate vulnerability zone among all covering 47 % of the total study area. But since no zone is fully protected from pollution, relevant authorities should concentrate their efforts on all of them. Since the northwest is more prone to pollution, cautious planning is required there as well. This index map will serve as the study's foundation for creating groundwater safe zones extraction and managing the local decline of the current environmental norms. A key component of any effective groundwater management plan for the region should be the groundwater susceptibility zone.

Extensive time domain monitoring of groundwater quality is essential to update the different levels of pollutants.

5.2 Recommendations

After utilizing the DRASTIC methodology and mapping out vulnerabilities. Considering each of the essential elements of the DRASTIC model, the following recommendations are made:

a) The assessment of groundwater susceptibility is a key instrument in water resource management. due to the fact that threat assessments and groundwater systems will benefit from this evaluation. This assessment will aid in the formulation of recommendations for safety measures and remedies in this area.

b) Given that the created map shows the susceptibility index of each zone (Low, Medium, and High), decision- and policy-making authorities may find it extremely helpful in setting monitoring and safety standards. The DRASTIC index map can be used as a screening tool for tasks related to water management and source distribution.

c) The susceptibility map and evaluation should be considered when creating land use policies. The map might be a useful tool to educate and motivate individuals to contribute to the preservation of the groundwater in their local area.

d) A vulnerable map of the entire nation, especially the industrial zones, should be made in order to lessen the possibility of groundwater pollution and recommend suitable preventive actions

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Appendices

Water table data of the study area				
Sample No.	**Location Description**	**Latitude**	**Longitude**	**Water Depth**
1	Korang Road I-10	33.6441	73.0312	200
2	I-9	33.6571	73.0509	250
3	I-8	33.6639	73.0644	200
4	G-9	33.6894	73.0422	200
5	G-8	33.695	73.0451	100
6	G-7	33.7105	73.0635	140
7	G-6	33.7121	73.0992	160
8	G-5	33.7236	73.095	25
9	Barakahu	33.7364	73.1716	300
10	Barakahu II	33.7351	73.1694	40
11	F-6	33.7217	73.0698	120
12	F-8	33.7124	73.031	250
13	G-10	33.688	73.018	150
14	G-11	33.6733	72.9916	190
15	F-11	33.6841	72.9853	350
16	D-12	33.7011	72.9694	325
17	I-11	33.6393	73.0239	280
18	G-15	33.6344	72.9231	305
19	G-14	33.6398	72.9575	350
20	Nilore	33.6537	73.2401	65
21	P. Sectrate	33.7387	73.0975	85
22	Ghuri Town	33.6218	73.1263	210
23	Tableghi Markaz	33.6201	72.9314	180
24	Chak Shahzad	33.6542	73.1383	90
25	PWD	33.5767	73.1482	225
26	Tarnol	33.6505	72.9041	150

Aquifer Media Data		
Lithology	**Latitude**	**Longitude**
Sand+Gravel	33.6693278	73.1061917
Clay	33.7076667	73.0361
Clay	33.6035111	72.9434194
Clay	33.6783333	73.005
Clay	33.7194444	73.0444444
Clay	33.74387741	73.17234039
Clay	33.75392914	73.16423798
Clay	33.75729752	73.16828918
Clay	33.73836899	73.14234924
Clay	33.75165176	73.14971924
Clay	33.69811249	73.07233429

Clay	33.63911438	72.95750427
Clay	33.6588889	73.0547222
Clay	33.74236679	73.15687561
Clay	33.7342186	73.14770508
Clay	33.72646713	73.15820313
Clay	33.68961334	73.05603027
Clay	33.67506409	73.02851868
Clay	33.66137695	73.00434875
Clay	33.70499039	73.04748535
Clay	33.70228958	73.04220581
Gravels	33.6680556	73.0641667
Gravels	33.6666667	73.0527778
Gravels	33.6680556	73.0644444
Gravels	33.6783333	73.0625
Gravels	33.6833333	73.0152778
Shale	33.6866667	73.1958333
Shale	33.6408333	73.15
Shale	33.74734497	73.16053009
Shale	33.75198364	73.14470673
Shale	33.69031525	73.09849548
Shale	33.6749115	73.01756287
Boulders	33.7239111	73.0744667
Sand+Gravel	33.6866972	73.1187333
Sandstone	33.6727778	73.0125
Sandstone	33.6958333	73.0166667
Sandstone	33.74427032	73.16156006
Sand+Gravel	33.6496222	73.0301889
Sand+Gravel	33.6706056	73.1080361
Clay	33.7297222	73.1241667
Clay	33.6722222	73.0822222
Clay	33.7027778	73.0263889
Clay	33.6958333	73.0083333
Clay	33.64551926	72.96995544
Gravels	33.6924889	73.1122361
Gravels	33.6531528	73.0538083
Gravels	33.6918306	72.9962694
Gravels	33.685775	73.022125
Gravels	33.6597222	73.1177778
Gravels	33.6627778	73.0727778
Gravels	33.695	73.0513889
Gravels	33.6855556	73.0672222
Shale	33.6361417	72.9789333
Shale	33.6866667	73.0347222
Shale	33.73865891	73.15131378
Boulders	33.6826083	73.0648444
Clay+Gravel	33.7022306	73.0209917

Clay+Gravel	33.6571278	73.0626389
Clay+Sand Stone	33.6725917	73.1689
Sand	33.72131729	73.15522766

Vadose Zone Media Data		
Lithology	**Latitude**	**Longitude**
Gravel+Sand+Clay	33.6693278	73.1061917
Gravel+Sand+Clay	33.7076667	73.0361
Gravel+Clay+Sandstone	33.6035111	72.9434194
Sandstone	33.6783333	73.005
Gravels	33.7194444	73.0444444
Sand+Clay	33.7438774	73.1723404
Sandstone	33.7539291	73.164238
Sand	33.7572975	73.1682892
Sandstone	33.738369	73.1423492
Sandstone	33.7516518	73.1497192
Sandstone	33.6981125	73.0723343
Sand	33.6391144	72.9575043
Shale	33.6588889	73.0547222
Clay	33.7423668	73.1568756
Clay	33.7342186	73.1477051
Clay	33.7264671	73.1582031
Clay	33.6896133	73.0560303
Clay	33.6750641	73.0285187
Clay	33.661377	73.0043488
Clay	33.7049904	73.0474854
Clay	33.7022896	73.0422058
Shale	33.6680556	73.0641667
Shale	33.6666667	73.0527778
Shale	33.6680556	73.0644444
Shale	33.6783333	73.0625
Shale	33.6833333	73.0152778
Shale	33.6866667	73.1958333
Shale	33.6408333	73.15
Clay	33.747345	73.1605301
Clay	33.7519836	73.1447067
Clay	33.6903152	73.0984955
Clay	33.6749115	73.0175629
Clay	33.7239111	73.0744667
Clay	33.6866972	73.1187333
Shale	33.6727778	73.0125
Shale	33.6958333	73.0166667
Shale+Clay	33.7442703	73.1615601

Gravel+Clay	33.6496222	73.0301889
Gravel+Clay	33.6706056	73.1080361
Shale+Gravels	33.7297222	73.1241667
Shale+Gravels	33.6722222	73.0822222
Shale+Gravels	33.7027778	73.0263889
Shale+Gravels	33.6958333	73.0083333
Clay+Sand	33.6455193	72.9699554
Gravel+ Clay	33.6924889	73.1122361
Gravel+Clay	33.6531528	73.0538083
Gravels+Clay	33.6918306	72.9962694
Gravels+Clay	33.685775	73.022125
Shale+Gravels	33.6597222	73.1177778
Shale+Gravels	33.6627778	73.0727778
Shale+Gravels	33.695	73.0513889
Shale+Sand	33.6855556	73.0672222
Shale+Sandstone	33.6361417	72.9789333
Shale+Gravels	33.6866667	73.0347222
Sandstone+Clay	33.7386589	73.1513138
Gravels+Clay	33.6826083	73.0648444
Gravels+Clay	33.7022306	73.0209917
Gravels+Clay	33.6571278	73.0626389
Sand+Clay	33.6725917	73.1689
Sandstone+Clay	33.7213173	73.1552277

Nitrate Data			
Sample No.	**Latitude**	**Longitude**	**Nitrates**
1	33.6441	73.0312	1.1
2	33.6571	73.0509	0.14
3	33.6639	73.0644	2.21
4	33.6894	73.0422	0.41
5	33.695	73.0451	0.21
6	33.7105	73.0635	0.48
7	33.7121	73.0992	0.28
8	33.7236	73.095	0
9	33.7364	73.1716	0
10	33.7351	73.1694	0.55
11	33.7217	73.0698	0
12	33.7124	73.031	0
13	33.688	73.018	0
14	33.6733	72.9916	1.86
15	33.6841	72.9853	0.07
16	33.7011	72.9694	0.21
17	33.6393	73.0239	1.38

18	33.6398	72.9575	0.76
19	33.6537	73.2401	2.41
20	33.7387	73.0975	1.1
21	33.6726	73.283	0.41
22	33.6218	73.1263	0.83
23	33.6201	72.9314	0.34
24	33.5707	73.1482	0.28
25	33.7083	73.1639	1.52
26	33.5998	73.1474	0.9
27	33.5667	73.1758	0.83
28	33.5738	73.2023	0.34
29	33.5464	73.1886	0.28
30	33.5124	73.1812	2.07
31	33.5256	73.1424	0.41
32	33.6132	72.8682	0.34
33	33.6853	72.8318	0
34	33.7606	73.2182	0.83
35	33.7435	73.198	0.55
36	33.6199	72.9808	1.03
37	33.6505	72.9041	2.34

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